



## **An Ecological Perspective on Insight Problem Solving**

Sune Vork Steffensen

University of Southern Denmark

and

Frédéric Vallée-Tourangeau

Kingston University

### **Author Note**

Correspondence concerning this chapter should be addressed to Sune Vork Steffensen, Centre for Human Interactivity, Department of Language and Communication, Campusvej 55, DK-5230 Odense M, Denmark, [s.v.steffensen@sdu.dk](mailto:s.v.steffensen@sdu.dk), or Frédéric Vallée-Tourangeau, Department of Psychology, Kingston University, Kingston-upon-Thames, Surrey, UNITED KINGDOM, KT12EE, [f.vallee-tourangeau@kingston.ac.uk](mailto:f.vallee-tourangeau@kingston.ac.uk). We thank Linden Ball for comments on a previous version of this chapter.

### **Abstract**

Our starting point in this chapter is the ecological tradition's aspiration "to understand how organisms make their way in the world, not how a world is made inside of organisms" (Reed, 1996, p. 11). For an organism, "making one's way in the world" is a continuous process: it is a behavioural and metabolic continuity where the organism-environment relation is regulated in a way that leaves traces in both the organism and the environment. The prerequisite for describing the organism-environment relation as being regulated is that the relation is sufficiently flexible: A living system's flexible, adaptive behaviour is enabled by cognition. Accordingly, a cognitive trajectory intertwines with the organism's behavioural and metabolic processes. We define this cognitive trajectory as an emergent pattern in a dynamic organism-environment relation, managed by the organism through continuous action-perception cycles. On this view, cognition does not play out in a separate, mediational (mental) realm, nor does it constitute a causal power that controls the organism's metabolic and behavioural states. The chapter opens with a critical review of the mentalist view on cognition and problem-solving, partly through a critique of the classic methods of decomposing problem-solving, partly through a discussion of Ohlsson's (2011) framework. After that we present the ecological framework and suggests that from that perspective, problem-solving psychology is the "psychology of the suspended next." We clarify this view through a presentation of how organism-environment interactivity gives rise to distinct cognitive trajectories in two case examples: one observed under laboratory conditions, and one in the 'wild'. Our main proposal is that to understand problem-solving, we need to take as a starting point how agents probe their cognitive ecology when their automatized routines fail and they find themselves confronted with an impasse. Insights, on this view, are not achieved, but enacted.

### **An Ecological Perspective on Insight Problem Solving**

A problem is solved when the world manifests a solution, that is, once the world has been shaped to overcome the difficulties or challenges posed by the problem. When, as observers, we identify an agent's solution to a problem, we note how the agent shaped the physical environment to address the problem. In doing so, we assume that a finished form implies a designer and a plan (cf. Dawkins, 1986; Ingold, 2014) from which matter was molded into a solution. However, this assumption reflects a hylomorphic bias (Ingold, 2010) that has imbued much work in creativity and the psychology of problem solving. We argue, however, that this is an unproductive, and possibly misleading, perspective on problem solving: Solutions may be enacted over time and space, but the trajectory and the end product may not evidence the design and implementation of a plan. Take the Acheulean hand axe: the earliest forms in the archaeological record date from 1.5 million years ago (Lycett & von Cramon-taubadel, 2008) and were symmetrically shaped (Malafouris, 2010). This symmetry is an interesting problem solving enigma: did our *Homo erectus* ancestors plan the symmetry or was the symmetry a consequence of manufacturing efforts? Malafouris (2010, p. 17) encourages us "to abandon our common representational/internalist assumptions, and recognize knapping as an *act of thought*" (emphasis in the original). He argues that the manufacturing intention is realized through engaging with the physical properties of the stone and the hammerstone. In other words, the intention and the resulting symmetry are emergent properties of the manufacturing process; they do not precede manufacture but rather are brought forth through manufacture.

The role and importance of interactivity and engagement with the material world, and the more general consideration of the cognitive ecosystem (Hutchins, 2010) within which thinking is enacted,

is underplayed or ignored in traditional problem solving research (with important exceptions, such as Kirsh, 2009). In this chapter we aim to demonstrate the crucial relevance of considering the material and interactive context of reasoning for insight. We open the chapter with a review of the prevailing mentalist paradigm as eloquently outlined by Ohlsson (2011). We then explore how cognition serves organisms, and draw much of our exposition from Anderson's (2014) arguments on neural reuse and the interactive brain that underscore the poverty of the mentalist paradigm. We outline what an ecological perspective on problem solving entails theoretically and methodologically. We close the chapter by reviewing some of our recent work on problem solving under laboratory conditions and in the wild that proceeds from an analysis of the tools and levels of interactivity promoted by different cognitive ecosystems.

### **Problem Solving as the Mentalist Sees It**

Many attempts have been made to decompose the complexity of problem-solving by identifying various relevant parameters. For instance, Schraw, Dunkle, and Bendixen (1995) distinguish between two different problem types: ill-defined problems and well-defined problems. The distinction depends on the degree to which the problem has a specific goal, a clearly defined solution path, and a clearly defined solution. Another distinction is between different process types: analytic problem-solving processes (based on deductive and inductive reasoning) and insight problem-solving processes which requires a (spontaneous or laborious) change of perspective on the problem (e.g., Fleck & Weisberg, 2013). Finally, it is widely acknowledged that problem-solving in experimental settings differs from problem-solving in everyday activities (Kirsh, 2009; Ormerod & Ball, in press). Thus, problem solving differs between different situation types and between different problem domains (medicine, mathematics, sports, etc.).

While such typologies are conducive to an overview of the field, the identified dimensions are conspicuously static: they present us with a view where unchanging agents face unchanging problems in an unchanging setting, depending on unchanging cognitive processes. The typological dimensions also have a strikingly circumstantial character. Although problem solving by definition is a process from problem to solution, the above categories focus less on actual processes, and more on circumstantial parameters. Even the distinction between analytic problem-solving processes and insight problem-solving processes, usually transmogrifies into a problem typology. For instance, Gilhooly and Fioratou (2009:362) make a “distinction between insight and non-insight [= analytic] problems” (not processes). Such distinctions build on the assumption that the problem-solving process is causally determined by the problem type (mediated by a mental problem representation; cf. Bowden & Grunewald, this volume).

What these considerations show is that, like all other fields, problem-solving research is scaffolded by a set of theoretical and methodological assumptions. And like in all other fields, one must regularly reflect on the appropriateness of such assumptions. To take one example, Ohlsson (2011: ch. 2) presents these assumptions explicitly. Ohlsson’s starting point is the founding assumption of classical cognitive science, namely “the insight that an intelligent agent [...] can be modeled in a precise way by specifying its representations, its basic processes and its control structure” (Ohlsson, 2011, p. 37). According to this assumption, “to explain a behavior (or a regularity therein) is to specify a program, that is, a control structure, a set of processes and a stock of representations, that generates this behavior (or regularity)” (p. 37). A cognitive psychology along these lines is named mentalism, “if it needs any other name than common sense” (p. 28). From a mentalist point of view, “mind is the proper subject matter of psychology” (p. 25), and “mind is a system” (p. 28) that “consists of representations” (p. 29). Further, Ohlsson adds to this system a number of “cognitive

functions like seeing, remembering, thinking and deciding [that] are implemented by processes that create, utilize and revise representations. The processes are coordinated by a control structure” (p. 29). The central notion here is that of representations: on the one hand, processes of transforming representations constitute cognitive functions, while they, on the other hand, are coordinated by a “central executive.” Ohlsson offers us two proofs for the existence of representations. First, “the exercise of visualizing something that is not present proves that mind is representational” (Ohlsson, 2011, p. 30), and second “our ability to mentally manipulate the present, the past, the future, the abstract and the fantastical highlight and prove the representational nature of mind” (p. 31).

### **The Shortcomings of Mentalism**

As noted by Ohlsson, the mentalist position has been criticized from different quarters (Anderson, 2003, 2014; Anderson, Richardson, & Chemero, 2012; Froese & Di Paolo, 2011; Gibson, 1966, 1979; Hutchins, 1995, 2010, 2014; Robbins & Aydede, 2009; Thompson & Stapleton, 2008; Varela, Thompson, & Rosch, 1991). One point of critique is launched against the idea that the task of the mind is the same as that of a scientist facing the world, namely to carry out inferences (Anderson, 2014). In order to allow the individual to navigate in the world, the mind establishes models of how the world functions: “from incomplete and fragmentary data, one generates hypotheses (or models) for the true nature of the world, which are then tested against and modified in light of further incoming sensory stimulation” (Anderson, 2014, p. 121). Accordingly, “cognition is post-perceptual—even in some sense a-perceptual—representation rich and deeply decoupled from the environment” (Anderson, 2014, p. 121). The inferential process thus converts sensory input into a map of the world, according to which the individual can act in the world. Two important objections can be offered. The first is that off line cognition that manipulate mental content may be “common among academics and can sometimes be induced in experimental

subjects, but it is relatively rare in the global cognitive ecology. It is also deceptive. Far from being free from the influences of culture, private reflection is a deeply cultural practice that draws on and is enacted in coordination with rich cultural resources” (Hutchins, 2010, p. 792). Second, generalizing from such systems assumes that there is a single class of intelligent agents, and that “animal, human, robot or space alien” (Ohlsson, 2011, p. 37) is each part of that class. This is a category mistake. Unlike computers and calculators, brains are not primarily in the business of constructing observer-independent models of the world; rather they are in the business of getting us around and managing our interactions with the world.

The Turing-Newell tradition (e.g., Newell, Shaw, & Simon, 1958) contributed heuristic models that describe behaviour. But a model is not an explanation. A model only functions as an explanation under the assumption that the model has a real-life ontological correlate, and representations have not been shown to have such a correlate. In fact, it might even be impossible to do so, because the model specifies the agent’s “representations, its basic processes and its control structure independently of their material embodiment” (Ohlsson, 2011, p. 37). The real-life physical correlate of representations is exactly a matter of their material embodiment.

### **Towards an Ecological Alternative**

To explain a behavioural pattern, it must be kept in mind that living beings are not primarily cognizers preoccupied with modelling the world; their task is to make their way in the world, seeking out opportunities and avoiding dangers. Accordingly, the task of psychology is “to understand how organisms make their way in the world, not how a world is made inside of organisms” (Reed, 1996, p. 11). For an organism, “making one’s way in the world” is a matter of upholding homeostasis through the regulation the organism-environment relations. The prerequisite



for describing the organism-environment relation as being regulated is that the relation is sufficiently flexible: the organism must be able to adapt to its environment—or make its environment adapt to it—and it must be capable of exhibiting behavioural flexibility under different circumstances. Accordingly, the basic *raison d'être* for cognition in living beings is to exert such flexible, adaptive behaviour that allows individuals (or groups) to regulate the organism-environment relation.

Second, having established how cognition serves living beings, we can now turn to the question of how it works. An ecological account emphasizes the real-time coupling between action and perception without “epistemic mediators” (Anderson, 2014, p. 138). Thus, perception is neither inferential nor representational: it is exploratory and performative. A living being probes its environment in order to detect action possibilities. Within the ecological tradition, Gibson (1979) coined the term *affordance* for those action possibilities. An affordance is a relation between the organism and the aspect of the environment that constitutes the action possibility<sup>1</sup>. As affordances are relational, they depend not only on relatively invariant features of the environment, but also on the organism’s ability to engage in a given activity (e.g., Schnall, Zadra, & Proffitt, 2010).

A non-representational model of cognition as embedded in action-perception cycles is not contradicted by Ohlsson’s examples of visualising absent structures and imagining the future. We typically visualise something in order to engage in an activity, such as drawing absent or past structures, deciding on future holiday plans, or understanding Ohlsson’s argument. This is

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<sup>1</sup> As argued in Steffensen (2016), the relationality of the affordance is a “thick relation.” A thick relation implies that “it is not the relation per se that constitutes the affordance, but rather the iterative interactivity through which the agent upholds the relation, perceives environmental structures, and acts in the world” (Steffensen, 2016, p. 36). Further, “given its relational thickness, an affordance is nonlinear, dynamical and inherently unstable: stretches of interactivity may bring forth affordances that were hitherto unnoticed. Such small changes in the layout of affordances may [...] create a large-scale restructuring of the layout of affordances that in turn bring about observable changes in behaviour” (ibid.).

compatible with an action-perception model, if the action-perception cycles are allowed to function on multiple timescales (Steffensen & Pedersen, 2014): Perceptions at time  $t_n$  may condition actions at time  $t_{n+1}$ , given that the organism-environment relation supports a sufficiently rich memory. This memory can be described as a representation, but as long as we cannot pin down its biological manifestation, the “representation” is merely a proxy for something still not understood.

The third implication is of a methodological nature. It has to do with how mentalism has shaped the design and interpretation of problem-solving experiments. Thus, when Ohlsson (2011, p. 26) for instance assumes that “to understand why the person performed the task at hand in the way he did, we need to know what he was thinking,” the rationale is that the performance is caused by thinking: “Speaking metaphorically, behavior is the end result of chains of billiard-ball-type interactions among representations.” (Van Orden, Holden, & Turvey, 2003, p. 332).

A general problem is that since mentalism builds on the metaphor of efficient cause, the Newtonian metaphor “strictly limits discoveries to cause-and-effect relations” (Van Orden et al., 2003, p. 332) between representation and behaviour, between inner mind (cause) and outer behaviour (effect). This gives rise to the problem of why an agent opts for one action rather than another (or none at all). For the Newtonian model to work, the mind has to contain a specific kind of intentional representation: “Intentions are representations that set in motion a causal chain. To have the intention to act is to cause the act to happen” (Van Orden et al., 2003, p. 332). However, as Van Orden and colleagues observe, the weakness of this view is that “intentional acts remain forever groundless, open ended, mysterious, or magical. How do intentions come into existence? What is the cause of the cause of purposive behavior?” (Van Orden et al., 2003, p. 332).

### **The Suspended Next**

Cognition enables us to get along in our lives. It is an unbroken trajectory that intertwines with the organism's behavioural and metabolic processes. Thus, we can define a cognitive trajectory as an emergent pattern in a dynamic organism-environment relation, managed by the organism through continuous action-perception cycles. A cognitive trajectory exhibits both continuity and discontinuity: on the fast bodily timescale of action-perception cycles it is continuous, but on a slower event timescale it self-organizes episodically (Steffensen & Pedersen, 2014; Uryu, Steffensen, & Kramsch, 2014). We are specifically interested in understanding the specific changes in the cognitive trajectory that we refer to as problem solving. Even a first glance indicates that problem-solving accords with the overall description above: it is a dynamical process that reconfigures the organism-environment system from a situation in which the agent is stuck to a situation where the agent moves forward. Typically, it is structured as two discontinuous equilibria: stabilized phases of first unsuccessful then successful attempts at solving the problem are interrupted by a short episode of overcoming the impasse of the first phase.

In itself, this structural similarity does not warrant that the ecological model can be transferred into the realm of problem-solving psychology. After all, there are important differences between the kinds of situations investigated by ecological psychologists and problem-solving psychologists. The former group is occupied with problems like the outfielder problem—"how does an [baseball] outfielder put herself in a position to catch a fly ball?" (Anderson, 2014, p. 137) —or selecting and throwing objects (Anderson, 2014, p. 129). Such problems are characterized by a high degree of behavioural fluidity: the outfielder engages in continuous action-perception cycles that allow him/her to navigate on the field, and the thrower can interact with the different artefacts in order to

select the preferred one for throwing. It is worth considering how problem solving differs from the phenomena studied by ecological psychologists.

What is so noteworthy for problem-solving tasks is the interruption of the basic action-perception continuity. If we accept Anderson's premise that "the fundamental cognitive problem facing an organism [is] deciding what to do next" (Anderson, 2014, p. 135), problem-solving psychology studies situations where "next" is suspended. While most people "know" how much to pay for ten apples if they each cost 20 pence (i.e., they can automatically pick a £2 coin in their purse), most will face a problem finding out how many 2 cm x 2 cm tiles are needed to cover a 5 m x 6 m floor. In such situations we are forced to suspend our automatised action-perception cycle and depend on incremental methods, based on prior experience with simpler versions of the task ("one square meter requires 50 times 50 tiles, i.e., 2,500 tiles; 5 m x 6 m is 30 square meters; then I need 30 times 2,500 tiles, i.e., 3 times 25,000 tiles, i.e., 75,000 tiles!"). Problem solving sometimes involves the improvised assembly of elements in such a manner that the engineered solution assigns new functional roles to the different elements. Famously, Mission Control had to improvise a rig to adapt a carbon dioxide scrubber to fit the lunar module, using only artefacts also found on board the spacecraft during Apollo 13 (Augier, Shariq & Vendelø, 2001). More prosaically, participants in Duncker's candle problem are tasked with discovering how to attach a candle to a vertical surface, with the candle, matches and box full of push pins as material (Duncker, 1945). Given the unusual character of such situations, agents rarely have prior experience with the specific problem. Crucially, the handyman, the NASA engineers, and the Duncker participants face situations where the basic action-perception cycles that characterize all living systems are insufficient for achieving a goal: "what to do next" (Anderson, 2014, p. 135) is obfuscated because there is no next from the

agent's point of view. Therefore, from an ecological point of view, problem-solving psychology is *the psychology of the suspended next*.

It is characteristic of the suspended next that the lack of experience-based solutions forces the agent to think, that is to search the problem space in order to come up with possible solutions. In a mentalist interpretation, this is evidence for the existence of a rich inner representation that can be investigated by the agent. This may be, but it does not entail that this form of 'thinking' is representative of problem solving in the wild. As Clark (2010, p. 24) puts it "we often do lots of stuff entirely in our heads, using inner surrogates for absent states of affairs. But it is surely worth noticing just how much of our cognitive activity is *not* like that; brains like ours will go to extraordinary length to *avoid* having to resort to fully environmentally detached reflection (...)". Rather, faced with the suspended next, agents seem to resort to action-perception cycles that function as "solution-probing" (Steffensen, 2017): by using models (Cowley & Nash, 2013), artefacts (Fioratou & Cowley, 2009; Vallée-Tourangeau, Abadie, & Vallée-Tourangeau, 2015), or properties of the environment (Steffensen, 2017), agents depend on interactivity to come up with a solution. If one accepts the view that problem-solving psychology is the psychology of the suspended next, it follows that both ecological psychologists and problem-solving psychologists are concerned with cognitive ecosystems (Hutchins, 2010, 2014). Hence, the difference is not one between ecologically embedded cognition and mentally-based cognition rather, the main difference is the level of automaticity with which agents explore and exploit the system.

Unfortunately, this point has been neglected because problem-solving psychology—given its mentalist assumptions—has created an impoverished, desert-like cognitive ecosystem, typically consisting of an agent, a piece of paper and a pencil (Vallée-Tourangeau, 2014). To counter this

approach, we call for a problem-solving psychology that takes a starting point in the “lay-out of affordances” (Chemero, 2000) for problem solving. Rather than resorting to models of an abstract problem space, an ecological approach to problem solving takes a starting point in how agents probe their cognitive ecology, with a particular view to how agents animate the organism-environment system when their automatized routines fail and they find themselves confronted with the suspended next. Insights, on this view, are not achieved, but enacted. Ippolito and Tweney (1995) stressed that “the process of insight is only explainable when the setting is carefully examined. Insights emerge from a dynamic blend of context and behaviour.” (p. 435)

### **Interactivity: Charting Cognitive Trajectories**

We now turn to the question of what a post-mentalist position implies for problem-solving psychology. Following recent work in “Distributed Language and Cognition” (Cowley & Nash, 2013; Cowley & Vallée-Tourangeau, 2017; Kirsh, 1997; Steffensen, 2012, 2017, 2015), we refer to the agent’s active adaptive engagement with the world with the term *interactivity* and define as sense-saturated coordination that gives rise to results (to adapt Steffensen, 2017). Coordination is key because the organism, in order to stay alive, is bound to uphold far-from-equilibrium homeostasis through regulating the organism-environment relation. This regulation amounts to a coordination of material, energetic and informational processes between organism and environment. Breathing the fresh air, biting into an apple, throwing a stone, seeing a deer in the woods, are all coordinative processes that depend on bodily movements in the environment.

One class of coordinating processes stand out, namely those that require a reciprocal flow of intercorporeal movements, prototypically between two conspecific organisms. Embracing one’s spouse, ordering a pizza, chit-chatting on the beach, are all coordinative processes that depend on

intercorporeal movements between two or more agents. From a phenomenological and ethical point of view, the two types of coordination differ widely because we relate to another human, as well as to many animals, significantly differently from how we relate to air, rocks and apples. But seen from a basic bodily perspective, the two types are similar: We only have one body, and we cannot separate it into different spheres that relate to different parts of our environment. The crucial difference, then, is that while the former type of coordinative processes is fully situated, the latter depends on the agent's ability to recruit situation-transcending (Linell, 2009) resources that can guide, enable or constrain the coordinative dynamics. If we compare two examples of vocalisation—e.g., shouting at a bear out of fear, and saying “hello” to one's neighbour—we would miss something important if we reduced them to just two acts of vocalisation. In the latter, the agent vocalises by drawing on a history of socioculture that constrains the vocalisation and the bodily movements (e.g., waving a hand). In other words, the coordinative processes are saturated with sense, that is, sociocultural resources through which past events impact on present events. Again, sense-saturated coordination between two human beings (e.g., a conversation, a dance, or a football match) differs from sense-saturated between a human agent and the non-human environment (e.g., the cultural significance of watching the sun set or smelling a rose). In the former case, “the involved parties must co-ordinate their activity [...]; all parties exercise power over each other, influencing what the other will do, and usually there is some degree of (tacit) negotiation over who will do what, when and how” (Kirsh, 1997, pp. 82-83). Whether there is one or more agents involved in some activity, we can describe it in terms of interactivity if it depends on real-time coordinative dynamics between agent(s) and the environment (including other agents), and if the bodily dynamics are sense-saturated. As such, a cognitive trajectory is an emergent pattern constituted by sense-saturated coordination of action-perception cycles between agents and between agents and the environment.

In our updated definition of interactivity, a third criterion is added, as it is required that the coordination gives rise to results. On the one hand, this seems a superfluous addition, in so far that coordinative dynamics change the relation between the organism and the environment, and such changes are clearly results of coordinative dynamics. On the other hand, if we only described behaviour at the level of action-perception cycles, we would miss the self-organising character of human behaviour. Thus, making coffee, riding a bike, writing an article, etc., all depend on action-perception-based coupling between agent and environment, and the action-perception cycles are in a sense continuous. At the same time, however, the examples illustrate that behaviour, on a timescale longer than the here-and-now, is discontinuous: assuming that interactivity involves action on multiple timescales (Steffensen & Pedersen, 2014; Uryu, Steffensen, & Kramsch, 2014), action-perception cycles self-organise into episodes that can be identified through the results they give rise to. In other words, interactivity depends on action on faster timescales, while it contributes to results on slower timescales.

The multi-scalar nature of human interactivity helps explain the changes along cognitive trajectories. Thus, because the coordinative dynamics of organism-environment systems are not taking place at a constant speed on a single timescale, they exhibit the same properties as punctuated equilibria, that is, longer periods of stability are interrupted by short periods of change (to borrow from Gould & Eldredge, 1977). The self-organised nature of human behaviour allows us to describe a cognitive trajectory by tracking the history of these reconfiguration points: when were results achieved? What were their enabling conditions? How did they emerge from interactivity? From Järvillehto's (2009, p.118) systemic psychology perspective: "the research should start from



the determination of the results of behaviour and lead to the necessary constituents of the living system determining the achievement of these results”.

### **Problem Solving in the Wild and in the Lab**

Having thus described interactivity as “the glue of cognition” (Kirsh, 2006, p. 250) that enables us to get along in our lives, individually as well as collectively, we now turn to the question of what this implies for problem-solving psychology. In particular, we are interested in understanding the specific changes in the cognitive trajectory that we refer to as problem-solving. Even a first glance indicates that problem-solving accords with the overall description above. It is inherently processual; it reconfigures the organism-environment system from a situation in which the agent is stuck to a situation where the agent moves forward. Typically, it is structured as two punctuated equilibria: a stabilised phase of unsuccessful attempts at solving the problem is interrupted by a short episode of overcoming the impasse, which in turn lead to a longer phase where the restructuring leads to results defined by the specific task under scrutiny.

In what follows we present two case studies of how a cognitive trajectory is enacted as a person and a dyad, respectively, face a suspended next, and overcomes it through a contingent pattern of action-perception cycles. We begin with a study of problem-solving in the lab, as that is the default object of study in problem-solving psychology. The case is a single subject solving the 17 Animals problem in a psychological laboratory in the UK. Our second case features problem-solving in the wild. It concerns two Danish office workers who struggle to make their electronic invoice system work.

**A “Pure” Insight Problem: 17 Animals.** We research problem solving in the lab by engineering thinking environments that afford different levels of interactivity. Our explanation of insight is bound to the environment through which it is enacted. This perspective makes unique predictions about the prospect of participants solving a problem in particular environments. Different cognitive ecosystems enact different forms of thinking and different problem solving trajectories, some that perpetuate an unproductive interpretation of the problem, others that bootstrap participants out of an impasse by drawing attention and shaping action possibilities that gradually encourage the formulation of a more productive interpretation of the problem. In our recent work we have used the 17 animals problem (henceforth 17A) to explore the cognitive ecosystem hypothesis.

The 17A problem is a ‘pure’ insight problem (Weisberg, 1995) requiring abandoning an arithmetic interpretation and adopting one involving overlapping sets. Participants read: how do you place 17 animals in four pens such that each one of the four enclosures contains an odd number of animals? The formulation lures participants to apply an arithmetic method to yield an answer. However, the direct transfer of well learned arithmetic skills and facts produces unsatisfactory solutions. The problem is simple and the conversational pragmatics suggests there is a solution; the participants anticipate only a momentary impasse. However, participants often cast aside their arithmetic intuitions, and labour the direct arithmetic method by listing odd numbers between 1 and 17 to determine, by selecting and discarding various combinations of 4 numbers, which ones can add to 17. This brute strategy, impervious to elementary arithmetic principles as they apply to whole numbers, does not work, of course. Still, we have witnessed participants pursue it for the full 10 minutes allocated to solving the problem. The impasse is broken once the the problem is seen as one involving the arrangement of sets and the distribution of individuated entities in set intersections rather than the manipulation of undecomposed number symbols (see Fig. 1).

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In a series of experiments (Vallée-Tourangeau, Steffensen, Vallée-Tourangeau & Sirota, 2016), we created two different cognitive ecosystems (Hutchins, 2010) by asking participants to solve the 17A problem in two different task environments within a 10-minute period. In one, participants were given a stylus and an electronic tablet to sketch a solution. In another, they were given pipe cleaning pieces and animal figurines to build a model of the solution. One environment favoured the application of an arithmetic solution: Participants drew four separate enclosures—either as separate circles or a cross splitting the work surface into quadrants—creating a static backdrop over which they laboured the arrangement of four odd numbers, primarily using whole number symbols rather than distributing individuated marks or dots corresponding to the 17 ‘animals’. This thinking ecosystem encourages the maintenance of an unproductive interpretation and problem solving attempts; in other words, it was harder for participant to bootstrap themselves out of a deep arithmetic groove. In the first of two experiments, no participants solved the problem this way, in the second, 17% did. In the model building condition, participants did not have a writing instrument, and hence could not employ and manipulate numerical symbols that cued the direct transfer of an arithmetic strategy; they had to solve the problems by distributing 17 individual pieces. More important, the pens themselves were the focus of intense scrutiny just by virtue of the fact that participants had to build them. The design and spatial layouts of the pens were no longer the static background over which numbers were slotted. Rather, participants worked on them, changed their shape, and size, and through this manufacturing process, exposed themselves to many different configurations. The model building ecosystem encouraged a figure-ground reversal, where the pens were as much the focus of attention as the numbers (Vallée-Tourangeau et al., 2015).

Participants were much more likely to solve the problem embedded in that interactive ecosystem (43% and 57% across two experiments<sup>2</sup>) than in the ecosystem with stylus and tablet.

These results suggest that a characterization of the task ecology is a key requirement in the developing a theoretical account of problem solving. The model building ecosystem produced a malleable problem presentation: Participants' actions modified key features of the problem, which produced a higher rate of solutions. An impasse is overcome by acting in the world. A dynamic protomodel of the solution cues certain actions, guides the allocation of attentional resources, which lead to physical modifications and a shifting topography of action affordances. Thinking in this ecosystem is less internal and more likely to be governed by actions and action affordances. Some of these actions may not be guided by a plan or specific hypotheses (Steffensen et al., 2016) and reflect un-mediated perception-action loops. In these experiments, there is evidence that the problem is restructured as reflected in the manner in which the physical features of the problem are constructed. Thus restructuring is physically manifest, and we would argue that a more productive interpretation of the problem dovetails the changes in the world, it does not anticipate them, or cause them. A workable solution to the problem is not planned and realized all at once: it emerges along a contingent spatio-temporal trajectory. That trajectory in fact charts the genesis of insight, it is not predicated on an insight.

These results underscore the importance of taking a systemic view of thinking. Minimally, a system is an agent-environment configuration wrought through interactivity. The system is a dynamic set of resources, some internal to the reasoner, others external, that are assembled to scaffold cognitive processes. The nature of the external resources, and of the singular system that is configured, will

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<sup>2</sup> In the second experiment, participants were given pre-formed hoops with which to build models (see Vallée-Tourangeau et al., 2016, pp.199-200).

determine the range of actions, the type of interactivity, which in turn will favour some results over others. Problem solving as observed in our lab with the 17A problem is largely explained by the type of system the agent-artefact coupling produced. Using the method of Cognitive Event Analysis, Steffensen et al. (2016) analysed the video recording of one successful participant in some detail: over 1200 annotations for a 10-minute session. For the first two minutes the participant spent time building enclosures. In the process, she created overlapping pens on a number of occasions, which were promptly disassembled to maintain a configuration of 4 non-overlapping enclosures. Four minutes ensue during which the participant sought to distribute the 17 figurines in a manner to comply with the problem instructions. Frustrated with her inability to crack the problem, the participant placed all the animals in a heap in the middle of the work surface and then focused her attention on the pens. While fiddling with the shape of one enclosure, she accidentally created an overlap. She proceeded to remove it, but inhibited her action just as she was about to touch one of the pens. Immediately after, rather than dissolving the overlap, she created another two intersections by moving the two remaining pens, and with these three overlapping areas, she had achieved a configuration that cued some interesting possibility for her, possibilities that failed to stir new ways of distributing the animals earlier in the session. Accordingly, she now proceeded to distribute the animals to match the odd number constraint.

When did she solve the problem? She solved it when she constructed a working model of the solution. Did she solve it when she produced overlapping sets? We would argue that she did not, but rather sought encouragement from this new arrangement and then systematically worked at populating this new enclosure configuration and over time realized that it could work. Her actions in the first 6 minutes of the session appeared to be guided by a plan reflecting an incorrect arithmetic interpretation of the problem. She set out to build separate enclosures, and then laboured

a direct arithmetic strategy. But her actions at the event pivot, that is when she took advantage of an overlap, did not reflect a plan that is actioned; rather actions distilled a plan, a working solution was enacted rather than mentally simulated.

We may ask how or where such a problem solving trajectory fits in the traditional dichotomy between the business-as-usual (Seifert, Meyer, Davidson, Patalano, & Yaniv, 1995) and special processes camps. On the one hand, her solution is the result of a certain contingent path: how enclosures were built initially, how distribution efforts failed, how an accidental overlap was opportunistically seized and exploited to drive new distribution efforts. The event pivot at the 6-min mark is an important discontinuity but the significance of the overlap was noticed only at a certain point in the trajectory; earlier accidental overlaps were disassembled. Thus, we understand her success from a contingent-historical perspective of failures and adjustments, and in that respect the solution appears to reflect largely conscious analytic processes that chart a continuous path to a working model. However, we resist the temptation of taking sides in the business-as-usual vs special processes debate: This debate is couched in mentalist terms, and our aim is to stress the unproductive commitment to mentalism and methodological individualism that such a perspective—and debate— entails. The ontological locus of cognition is not the individual, it is the system. From an ecological perspective, problem solving is enacted. The working model of a solution is evidence of having solved the problem. The physical model was constructed into a working solution, but it is unfounded to say that the construction reflected the implementation of a plan (cf. Ingold, 2010).

**The Invoice Case.** The advantage of lab experiments is that the researcher can create a cognitive ecosystem that is likely to yield given behavioural outcomes. For instance, the 17A problem

description is formulated to encourage an interpretation that renders the problem initially unsolvable for most people. In real life, the ecological contingencies of our environment are sufficiently resilient and redundant to prevent such stabilised misinterpretations: First, rather than meeting tasks in the shape of written instructions, such as Duncker's "attach a candle to the wall, using only this box of tacks, these candles and these matches," we experience, say, a need of light above an area adjacent to a vertical surface. Second, while we all have anecdotal experiences that resemble the experiences of the lab subjects (e.g., the feeling of being lost and stuck because we have interpreted some environmental obstacle in a way that turned out to be wrong), the systematic documentation of such unexpected events is methodologically challenging.

The invoice case is remarkable because it is in fact an example where a misinterpretation of a naturalistic task (i.e., a task that emerges in a real-life ecosystem, without being designed to do so) leads to an impasse that is overcome in the same way as impasses are overcome in the lab. The invoice case features two Danish office workers, anonymised as Black and White (their respective shirt colour). The task facing the two protagonists is to utilise the computer software that generates the company's invoices, and which is provided by another department in the company. Seen from the vantage point of Black and White, the suspended next emerges because the invoices generated by the computer software do not contain a unique business identification number (the so-called CVR number) that enables the invoice receiver to pay the bill. Parallel to how the solvers of the 17A task are led to believe that their problem was an arithmetic one, Black and White are led astray by assuming that the root of the problem is a flawed software system that fails to print the CVR number in the invoice. Accordingly, their solution strategy is to feed the CVR number into the software, so it is printed along with the rest of invoice information. However, the solution is much more mundane: the CVR number already appears on the company's letterhead, and as such, there is

no need to print it again! The software programmers knew that, but Black and White miss this important point because they, for economic reasons, have tested the system by using blank print paper rather than the more expensive letterhead paper. For an overview of the situation, see Figure 2.

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INSERT FIGURE 2 ABOUT HERE  
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Steffensen (2013) traces a 55 seconds trajectory along which the cognitive ecosystem, animated by Black and White, realises that the solution to the problem is to choose another print tray in the software's print menu. This investigation also relies on Cognitive Event Analysis, and it shows how small variations in the repetitive structure caused by the suspended next in fact are crucial to overcome the impasse. More specifically, the cognitive trajectory goes through three cycles before the impasse is overcome. The cyclicity of the cognitive trajectory is conditioned by the organisational asymmetry between the two protagonists: Black is the main person responsible for the invoices and their interaction takes place at his desk. Accordingly, the main activity consists of Black *recapitulating* what the problem is, and as he does so three times, each recapitulation indicates a new cycle in their problem-solving.

The first cycle begins with Black's succinct description of the problem with the invoice: *but I can tell you there is no one whatsoever who will pay that invoice.*<sup>3</sup> From an informational point of view, Black's utterance is vacuous, as White is already aware of the shortcomings of the invoice: *No, I am aware of that. That's why we told them that it was no good. But that was not our business because it was as agreed upon. That was it. But it might be that you can get a better answer, I was just told*

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<sup>3</sup> All utterances are translated from Danish into English. For the original Danish wording, see Steffensen (2013).



*that's was how it was.*<sup>4</sup> While White reports his exchange with the programmers, Black is looking for the CVR number, presumably in order to enter it manually into the computer. Accordingly, in this first cycle we both see the dyad's frustration with the other department and their fixation on the computer software as an input-output system. No solution is achieved.

Superficially, the second cycle resembles the first. It even starts with Black uttering the exact same five words: *But I can tell you...* The rest of his opening utterance does not add much new information either: *This one they'll just discard. This one they will never ever pay it. It will never get paid, this one.* However, while from an informational point of view, the second cycle is highly repetitious, it is not so from an interactivity-oriented viewpoint. Thus, Black's utterance contains three instances of the marked deictic *this one* (Danish 'den her', literally 'this here'), and each of them functions as nodal points that change the interactional dynamics between the two protagonists. Thus, while Black utters the first deictic (in *this one they'll just discard*), he picks up the flawed invoice printed on blank paper and holds it in his left hand (cf. Fig. 2). This action prompts White to reorient his attention, and now, like Black, he gazes on the invoice. After a 2.2 seconds long gaze at the invoice, the two men use the second occurrence of *this one* to redirect their gaze to each other, before Black – after 1.6 seconds eye contact – shakes the paper lightly at the thirds occurrence of *this one*. In other words, while the second cycle is largely a repetition of the first on an informational level, the dynamics in the dialogical system (Trasmundi & Steffensen, 2016) change significantly: the two subjects reorient their attention to the invoice, and it thus becomes an important cognitive artefact in the cognitive ecosystem.

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<sup>4</sup> In White's response, 'them' refers to the software engineers who have programmed the invoice software.

The importance of the invoice as a cognitive artefact capable of triggering changes in the problem-solving trajectory is evident in the third cycle. In this 8.6 s long sequence, Black once again states what the problem is, but the introduction of the new cognitive artefact prompts him to do so in a way that differs from the first two cycles. This difference is evident from both his words and his embodied behaviour. On a linguistic level, Black opts for a new strategy for stating the nature of the problem; thus, rather than describing the problem from his – or the company's – point of view, he now adopts the invoice receiver's point of view. This is apparent in his five consecutive utterances in this cycle:<sup>5</sup>

*If it were me then it was just thrown on the pile. (0.7)*  
*I can't pay that. (0.4)*  
*Why can't I pay it? (0.8)*  
*There is no CVR number on it. (0.9)*  
*you can't send an invoice without a CVR number. (0.4)*

The two central observations here are, first, that Black uses a well-known formulaic conditional (*If it were me*) to establish a hypothetical thought experiment, and, second, that the 'I' within this thought experiment is not himself, but rather the receiver of the invoice. Thus, the utterances *I can't pay that* and *Why can't I pay it?* only makes sense, if it is interpreted as Black's way of projecting the invoice receiver's reaction to an invoice without a CVR number. The 'I' refers, not to the speaker, but to the protagonist of Black's narrative, and the present tense of the modal verb 'can' does not refer to the time of speaking, but to the future point of time where the invoice is handled by the invoice receiver. Thus, from a linguistic point of view, Black recalibrates the deictic system: while normally, speakers organise their speech around a deictic origo of *I-here-now*, the deictic origo becomes virtual in Black's enactment of the invoice receiver's point of view.

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<sup>5</sup> The numbers in parentheses indicate length of the pauses between his utterances.

However, it is not only linguistic means that prompt Black – and consequently White as his interlocutor – to adopt the receiver’s point of view. Thus, during the first utterance, *If it were me then it was just thrown on the pile* (Danish, *hvis det var mig så røg den bare hen i stakken*), Black also enacts the receiver’s perspective. He lets go of the paper, which drops 3-4 cm, and he then catches the paper again (cf. Figure 3). Having caught the paper, Black then continues by moving his hand forward and throwing the paper into a pile of papers at the far end of the table.

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 INSERT FIGURE 3 ABOUT HERE  
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Crucially, the spoken and the embodied enactment of the invoice receiver’s perspective are finely synchronised. This synchronisation is documented in Figure 4 that shows a spectrogram of the utterance *If it were me then it was just thrown on the pile* (Danish, *hvis det var mig så røg den bare hen i stakken*), along with an indication of Black’s hand movements.

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 INSERT FIGURE 4 ABOUT HERE  
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The central element in Black’s narrative formula *if it were me* (*hvis det var mig*) is the 200 ms stressed syllable *me* (Dan. *mig*). This personal pronoun is the pivotal element in the recalibration of the deictic system: it bridges the perspective of Black to the perspective of the invoice receiver, which is presented in the subsequent main clause. This syllable coincides with Black’s catching movement: thus, the verbal and the embodied enactment of the receiver come together in a highly synchronised way. Interestingly, Black’s behavioural and verbal simulation of the receiver’s point of view prompts White to articulate the solution to the problem: *well no but it [the CVR number] is there if we print on logo paper*. It is thus White that picks up on Black’s cognitive work and turns it

into a problem identification: the problem does not pertain the computer software, but to the choice of printer tray!

Summing up the invoice case, it has given us a rare window into insight problem solving in the wild. Importantly, it emphasises the systemic nature of problem solving: Black and White navigate in a rich environment structured by the layout of the office (Kirsh, 1995; Perry, O'Hara, Spinelli, & Sharpe, 2003) and the presence of cognitive artefacts (Nemeth, Cook, O'Connor, & Klock, 2004). Evidently, space and things do not automatically produce cognitive outputs; the cognitive system is animated by human components, but even the two protagonists cannot be seen as isolated components: to come up with a solution, they rely on the interactivity that plays out between them (Harvey, Gahrn-Andersen, & Steffensen, 2016; Steffensen, 2013). In particular, Black investing himself in repeatedly stating what the problem is—with variations that accumulate into a non-linear change of perspective—functions as a probe that enables the system to reconfigure.

## **Conclusion**

Interactivity is at the heart of problem solving outside the psychologist's laboratory, and as we have shown in this chapter, it is possible to explore interactivity under laboratory conditions as well. The complexity and hence the creative arborisation potential is guided and constrained by the material artefacts offered. Tasks where participants can interact with a physical and malleable problem unveil a very different range of multiscale processes than when problems are presented as static verbal descriptions; in fact, they unveil very different reasoners, or more specifically they unveil how the reasoner-environment system does thinking. A physical model of the problem offers a physical record of the creative arc, the problem solving trajectory, and as an external storage device, it augments the systemic working memory resources. But this is not simply an external storage

story. The physical model, there to be examined and acted upon, reduces or eliminates the representational burden. So-called executive functions such as updating and attention shifting, are cued and governed by changes in the configuration of the problem elements. Problem solving is enacted at different time scales: unmediated actions are triggered by the shifting affordances at the faster end, and deliberate analysis of results at the slower end.

The acknowledgement of the multiscale character of problem solving provides us with a better understanding of one of the most characteristic behavioural tendencies of problem solvers facing an impasse: their recurrence to cyclical repetitions of behaviour. In the invoice case, Black cyclically repeated his perception of the nature of the problem, in the 17A case, many solvers dealt with impasses by resetting the problem presentation and starting all over, and the same tendency has been abundantly reported in the literature (e.g., Chu, Dewald, & Chronicle, 2007).

While these repetitions are cognitively vacuous from a mentalist point of view, because they do not indicate changes in computational processing, an ecological approach argues that “this repetition is not mere repetition because it is contextualized by actively perceiving the world” (Cowley & Nash, 2013:193). Cyclicity then becomes a way of investigating, or indeed creating, unnoticed affordances for problem solving. Repeating yourself can be sensible, exactly because the repetition will likely not be a perfect replication, and the small variations may lead to outcomes—not unlike how genetic variation can lead to mutations: “You cannot step twice into exactly the same idea” as Ingold (2014, p. 127) puts it. One can hypothesise that repetitions on an observational meso timescale (which tend to steal the attention because they are so salient for the observer) depend on micro-scale variations that changes the problem landscape, and that these in turn constitute macro-scale systemic transformations (i.e., what we observe as the agent solving the problem). On this

hypothesis, the creative arc in problem solving is constituted by a nested hierarchy of variation and cyclicity. More research is needed in order to establish on which timescales variation and cyclicity most optimally occur, and to establish how this multiscalar pattern depends on the nature of the problem, the solvers, and the ecosystems in which they are embedded.

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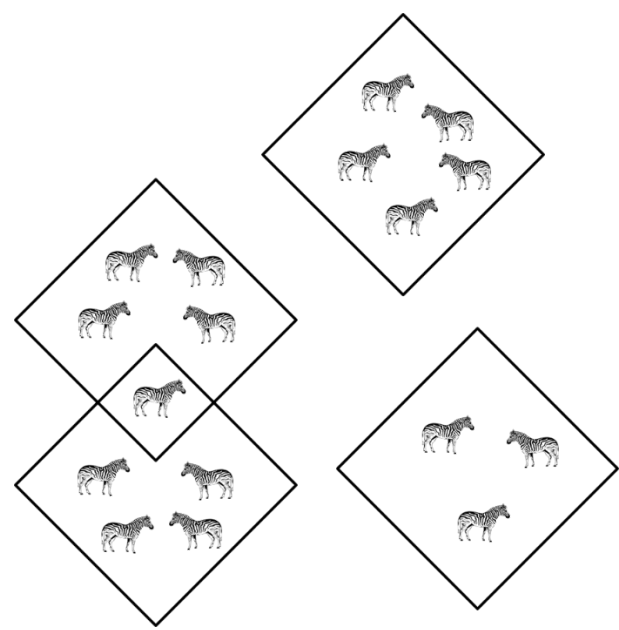


Figure 1. A solution for the 17 animals problem.



Figure 2. The cognitive ecosystem. Black is sitting at his desk with a print version of the flawed invoice in his left hand. White is standing next to him, holding a pile of task irrelevant papers in his hand.



Figure 3. Black enacts the imagined invoice receiver: he lets go of the paper and catches it again, thus embodying the “receiving movement” of the invoice receiver.

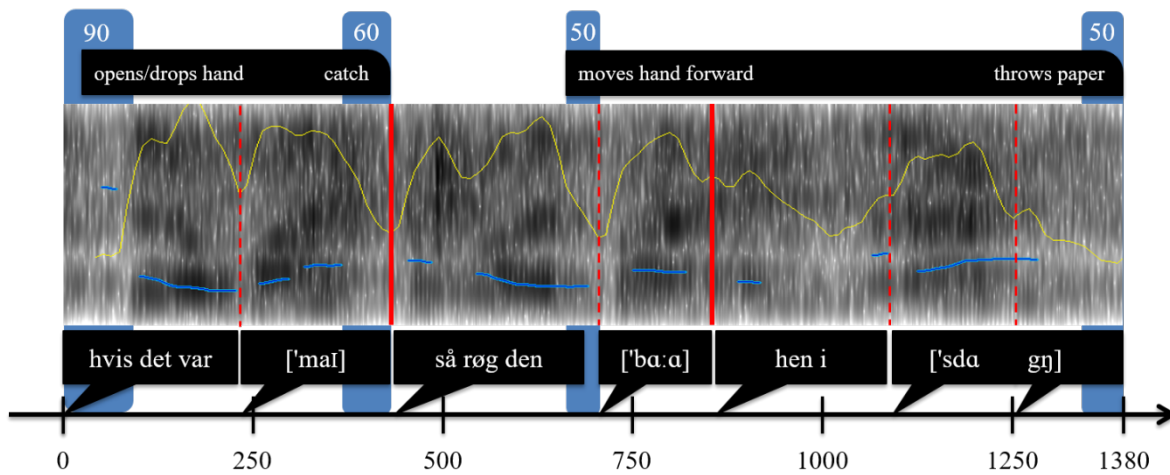


Figure 4. A spectrogram of Black's utterance *If it were me then it was just thrown on the pile* (Danish, *hvis det var mig så røg den bare hen i stakken*). The three stressed syllables *mig*, *bare*, *sta(kken)* (English, *me*, *just*, *(the) pile*) are rendered in phonetic transcription. Over the spectrogram, Black's hand movements are indicated. The blue squares indicate synchronisation between speech and hand movements: (i) beginning of utterance and beginning of hand movement (90 ms); (ii) catching the piece of paper and the stressed syllable *mig* (*me*) (50 ms); (iii) moving the hand forward and the stressed syllable *bare* (*just*); and (iv) end of utterance and letting go of paper that continues into the pile (50 ms).